Western Canada Coal Liquefaction Study Prefeasibility Study

Prepared for:
Western Canada Coal Liquefaction Study Consortium

Executive Summary

Kilborn Engineering (B.C.) Limited
May 1982

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Prepared for:

British Columbia Resources Investment Corporation
Petro-Canada Exploration Incorporated
Westcoast Transmission Company Limited
British Columbia Coal Limited
Energy, Mines and Resources Canada

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60pp

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1.0 PROJECT OVERVIEW

This document presents the results of a Prefeasibility Study to evaluate the potential for the liquefaction of two British Columbia coals, Greenhills and Monkman, to produce high quality synthetic crude and thereby reduce the province's dependance on outside sources of petroleum products. The synthetic crude would be upgraded to finished products -- transportation fuels, industrial fuels or home heating oil -- by existing refiners. This Prefeasibility Study is the first phase of a potential long term project to establish a commercial coal liquefaction facility in the province by the late 1980's to early 1990's.

Of the five processes nominated for evaluation, two (SRC-II and Exxon Donor Solvent) were eliminated on the basis of poor liquefaction yields predicted by the B.C. Research microautoclave test program. Further screening of the remaining three processes (H-Coal, Ruhrkohle/Veba and NCB/BP Liquid Solvent Extraction) was not possible based on yields predicted by the test programs or process developers predictions. Results of all the test programs indicated that the nominated B.C. Coals are difficult to liquefy and that low distillate yields, only in the range of 40 percent, are to be expected.

To assist the Western Canada Coal Liquefaction Study Consortium in deciding the next phase in the coal liquefaction project, capital cost estimates, annual operating cost estimates and annual product revenue estimates were prepared for a 'typical' coal liquefaction process, designed to process 10 000 tonnes per day beneficiated coal and yield an assumed 40 percent liquid distillates -- or a nominal 24 000 barrels per day of distillate products.

The H-Coal process was chosen to represent the 'typical' coal liquefaction process and Greenhills coal was selected on the basis of its marginally better distillate yields in the microautoclave test programs. This evaluation of the H-Coal process does not signify that it is better suited for the liquefaction of the B.C. Coals than the other two processes -- Ruhukohle/Veba and NCB/BP LSE. It was selected as representing all three processes for this evaluation on the basis of the quality of information available to Kilborn and Badger. Similarly, use of Greenhills coal does not preclude the future development of a coal liquefaction project with Monkman coal.

	Base Case
Estimated Capital Cost,	
$ Billion	2.02
$/BPD C_5^+ Product	832 000
Estimated Annual Operating Cost, $	393 080 000
Estimated Annual Product Revenue, $	437 500 000
Estimated Annual Gross Margin, $	44 420 000

All costs are in first quarter 1982 Canadian dollars. Product prices are based on the January 1982 new oil price as per the September 1981 Oil Pricing Agreement; coal price was set at $80.00 per tonne.

Based on the preliminary economic evaluation, the discounted cash flow rate of return for the Base Case is 4.6 percent. Alternate processing options, including higher distillate yields and residue processing to increase product yield, were evaluated with a view towards improved rates of return for the proposed project. Indicated rates of return for these options, discussed in this report, is 7.6 - 8.4 percent.

As an addendum, the effect of significantly lower new oil price forecasts contained in the Announcement of April 13, 1982 by the Province of Alberta. With this pricing structure, as discussed in this report, DCF rates of return were zero or negative for all cases at $80.00 per tonne coal and 4.3-7.7 percent at $50.00 per tonne coal.

Because the results of the preliminary economic evaluation are discouraging, further development of the coal liquefaction project should be approached with caution. Further development is warranted to answer major unknowns, in particular liquid distillate yield, identified in this prefeasibility study. The main emphasis of the recommended development program should be placed on the evaluation of process parameters that would make the project more attractive economically, including increased distillate yield, lower coal price or alternate source of coal that offers a better potential for liquefaction than Greenhills or Monkman coal. Continuous bench scale testing of the selected B.C. coal should be carried out to substantiate liquid distillate yields and the split between naphtha, middle distillate and heavy distillate fractions.

Only if results of the experimental programs can substantiate distillate yields in excess of 40 percent with a high percentage of naphtha and middle distillate fractions should a technical and economic evaluation of the leading process be undertaken to evaluate the economic viability of the proposed coal liquefaction project.

2.0 INTRODUCTION

Since British Columbia depends on extra-provincial supply sources for approximately 75% of its current oil requirements, the potential for liquefying native coals into petroleum substitutes deserves investigation. Coal conversion into liquid transportation fuels, using advanced liquefaction technology, could offer the opportunity for savings on oil imports, movement towards Canadian and British Columbian oil self-sufficiency and long term coal utilization. In recognition of this potential the Western Canada Coal Liquefaction Study Consortium was created to initiate the development of a coal-based synthetic liquid fuels industry in Western Canada. The members of the consortium for the Western Canada Coal Liquefaction Study are:

The British Columbia Resources Investment Corporation
Petro-Canada Exploration Inc.
Westcoast Transmission Company Limited

This study is part of the ongoing oil substitution program in Canada involving the Federal Government, Provincial Governments and private industry. Public support for the study was made available through the Canada Centre for Mineral and Energy Technology (CANMET).

In order to evaluate the potential of liquefying bituminous coals from the Monkman and Sparwood areas of British Columbia, the consortium retained Kilborn Limited to conduct a Prefeasibility Study. The primary objective of Kilborn's work was to assess the technical and economic feasibility of liquefying the coals in these locations. Kilborn retained Badger Energy Inc. of Cambridge, Massachusetts as a sub-consultant to provide assistance for this study.

The principal objective of the Prefeasibility Study was to evaluate the technical and economic feasibility of conversion of bituminous

coals in Eastern British Columbia to transportation liquids using direct liquefaction technology. The coals and processes to be considered in the study were selected by the Western Canada Coal Liquefaction Study Consortium. These selections, made prior to commencement of this study, were as follows:

Nominated Coals	Monkman
	Sparwood
Nominated Processes	SRC International Inc. (SRC II)
	Hydrocarbon Research Inc. H-Coal
	Exxon Donor Solvent (EDS)
	NCB/BP Liquid Solvent Extraction (NCB/BP)
	Ruhrkohle/Veba

Microautoclave and continuous bench scale test programs were conducted by B.C. Research and Sandwell Beak Research Group (SBRG), respectively, to evaluate the reactivity of the nominated B.C. Coals under conditions similar to those used by the process developers.

Test data developed by B.C. Research and SBRG were provided to the process developers as an aid in the evaluation of the potential of their processes to liquefy the nominated B.C. Coals. Limited testing was conducted by the National Coal Board (NCB) and Hydrocarbon Research Inc. (HRI) to better assess the capability of the NCB/BP Liquid Solvent Extraction (LSE) and H-Coal processes, respectively, to liquefy the high rank B.C. Coals. Their data, or the results thereof, are incorporated in the report. A test program, specific to the German process, is currently being conducted by Veba Oel; results will not be available in time, however, to be incorporated into this report.

As the test programs conducted by B.C. Research, SBRG and HRI and relevant literature information all predicted low distillate yields for the nominated B.C. Coals, it was decided to develop preliminary

costs and economics for a 'typical' direct coal liquefaction process utilizing Greenhills coal. It was further decided to evaluate the coal liquefaction process on the basis of the production of a coal-derived synthetic crude product, not finished transportation fuels as was the original concept. Specifications were established for the syncrude fractions (naphtha, middle distillate and heavy distillate) such that the syncrude product could be processed by other Canadian refineries to finished products -- transportation fuels and/or industrial fuels and home heating oil. Results of this technical and economic assessment would be used by the Western Canada Coal Liquefaction Study Consortium to decide the next phase in the development of the coal liquefaction project, should further development be warranted.

Order-of-magnitude capital and operating cost estimates were prepared for the H-Coal process, as being 'typical' of the direct liquefaction processes being considered. This selection does not imply that the H-Coal process has any technical or economic advantages over the other direct liquefaction processes. The selection of this process was made to expedite the feasibility study. Capital cost estimates were factored from major equipment budget prices for the H-Coal high pressure conversion unit, from process developer information and using in-house data. Operating cost estimates include allowances for the cost of operating and maintenance personnel; supervision and management staff; coal and natural gas feedstocks; utilities; catalysts and chemicals; maintenance parts; local taxes and insurance.

A preliminary economic analysis was prepared for the 'typical' H-Coal case. Sensitivity analyses to variations in capital, operating costs, the price of coal and gross revenue were conducted. Two product price structures were evaluated, one based on the January 1982 new oil price according to the September 1981 Oil Pricing Agreement and the other based on the April 13, 1982 Announcement by the Government of Alberta, both with discounts reflecting the lower-than-normal quality of the coal-derived syncrude product.

A comprehensive report was prepared by Kilborn and Badger Energy, which summarizes all of the information and data used in the completion of this Prefeasibility Study. Volume I of the report contains all technical aspects of the study, including the results of the coal testing programs and process evaluation, and provides a detailed discussion of conclusions and recommendations pertaining to further development of the proposed project. Capital cost estimates, operating cost estimates, product revenue estimates and the preliminary economic analysis are presented in Volume II. Details of the B.C. Research, SBRG and HRI test programs are provided in Volume III - Appendices.

3.0 TECHNICAL EVALUATION

3.1 Coal Testing Program

One of the major objectives set forth in the Prefeasibility Study was to select which of the two nominated B.C. Coals were best suited for liquefaction. The selection was to be made by performing laboratory tests on samples of the two coals selected by the Western Canada Coal Liquefaction Study Consortium. B.C. Research (BCR) was nominated to perform the first stage of the testing program which was a series of microautoclave tests on the Greenhills, Monkman and Illinois No. 6 coals. To obtain a direct comparison of the liquefaction potential of the B.C. Coals, Illinois No. 6 coal was used as a reference coal.

Based on the results of the microautoclave tests, optimum operating parameters were established for the liquefaction of the two nominated coals. These parameters were then used as a basis for the determination of operating conditions for continuous tests to be performed by Sandwell Beak Research Group (SBRG). The continuous test results were expected to indicate the maximum distillate yield and probable product slate for each coal.

The reactivity of the Greenhills and Monkman coals were tested under conditions similar to those used by the process developers. Under the limited test conditions, it is recognized that true simulation of any particular process was not possible. However, attempts were made to recreate the conditions used by the individual process developers; these attempts have been termed as 'model', 'modelling', 'simulate' or 'simulation', where appropriate, in the text.

In the first stage, microautoclave tests were performed by B.C. Research to 'model' four direct liquefaction processes. The two catalytic processes 'modelled' were the H-Coal process and the

Ruhrkohle/Veba (German) process. SRC-II and EDS were the two non-catalytic processes 'simulated'. It was not possible to 'simulate' the NCB/BP LSE process because of the limited scope of the work.

The Ruhrkohle/Veba process was 'simulated' using a coal-derived recycle solvent obtained from Bergbau-Forschung in Germany and Red Mud (Fe_2O_3) catalyst. The Red Mud, rich in Fe_2O_3, is a waste product from the Aluminum industry using bauxite as a feedstock. Hydrogenated anthracene oil was used as the solvent for 'simulating' the other three processes. The catalyst used in 'modelling' the H-Coal process was HDS 1442A, a Cobalt-Molybdenum catalyst used by HRI.

The B.C. coals were found to be less reactive than Illinois No. 6 coal. Conversions in the range of 40-68 percent were achieved (compared to 54-80 percent for Illinois No. 6), but the distillate oil fractions were only in the range of 25-50 percent.

The distillate oil yields were in the order of 10 percent higher in catalytic processes under similar conditions. On comparison of the two catalytic processes, the coal-derived solvent and Red Mud catalyst (German process) showed about 10 percent better yields. However, one test under similar operating conditions, with hydrogenated anthracene oil and Red Mud catalyst gave 10-18 percent lower distillate oil yield, indicating a very strong dependency on the nature of the solvent. In earlier tests with raw anthracene oil as solvent, the yields were much lower than with hydrogenated anthracene oil.

Having established the better performance of the catalytic processes, the basis for tests on the SBRG continuous process development unit were established. The two catalytic processes to be 'simulated' were H-Coal and Ruhrkohle/Veba. Hydrogenated anthracene oil was the common solvent used with both HDS and Red Mud catalysts.

The test using H-Coal catalyst was performed at the temperature and pressure normally used by the process licensor. Due to equipment limitations, the operating temperature for 'simulating' the Rurkohle /Veba process was about 30-35^{o}C lower than the recommended temperature.

Since a true coal-derived recycle solvent was not available, actual distillate yields could not be determined. Instead, a minimum and maximum range of distillate yields was calculated. This range was based on assumptions made on the solvent behaviour.

Using these assumptions, the distillate yields from the Monkman coal 'simulated' in the H-Coal process were between 19% and 34%. The Ruhrkohle/Veba 'simulation' with the Greenhills coal yielded between 18% and 34% distillates.

Again, high liquid yields were obtained, most of which was a heavy oil fraction or pitch. The absence of a true recycle solvent and, in the case of the Ruhrkohle/Veba process, lower than desired operating temperature is recognized as affecting distillate yields.

Both the SBRG tests were conducted under predetermined conditions and not experimentally optimized conditions. This was also recognized by the process developers who suggested that independent tests be performed by themselves, which would simulate recycle solvent operation to determine the liquefaction potential of the coals at optimized conditions.

HRI performed a set of microautoclave tests on the Greenhills coal to simulate recycle solvent operation of the H-Coal process. HRI claimed that their tests would provide data that could be correlated against their data bank and would enable prediction of the obtainable distillate yields via the H-Coal process. HRI predicted that, with recycle of the vacuum bottoms residue, 43% distillate oil yield could be obtained by the H-Coal process. The actual split of the

distillate oil fractions was based on assumptions made on the possible solvent behaviour--as in the SBRG tests. HRI predicted two extreme values of the distillate oil split:

1.8%, 5.8% and 35.4% as one extreme, and
3.7%, 19.9% and 19.4% as the other extreme

for the light distillate, middle distillate and heavy distillate fractions, respectively.

On reviewing the HRI report, it became evident that the results of the microautoclave tests conducted by B.C. Research and HRI were very similar, within acceptable experimental accuracy (about ±5%). Their test results also confirm the SBRG prediction that the B.C. coals are difficult to liquefy and most of the distillate oil thus produced is heavy oil.

Tests are also being conducted by Veba Oel in West Germany. The results are not expected to be available in time to be included in this report.

3.2 PROCESS DEVELOPER PREDICTIONS AND PROCESS SCREENING

3.2.1 Overview

The rationale behind approaching the process developers was to obtain their forecast of the performance of their process using the nominated B.C. coals to produce a synthetic crude product. The quality and the distribution of the products in the primary liquefaction stage were to be important considerations.

Each of the five process developers, HRI, Ruhrkohle/Veba, NCB/BP, Exxon and SRC International, were requested to make their predictions by methods they considered appropriate. These methods could be based on numerical models, batch and/or continuous experiments at

any scale with similar coals or their existing analytical data bank. To assist them in assessing their process, the analysis of the two coals, selected test results from the microautoclave tests performed by B.C. Research and, where appropriate, the selected experimental results from the SBRG continuous tests were provided.

The process developers were asked to provide sufficient information to allow development of a scaled plant prediction for conversion of 10 000 tonne per day of coal to liquid products, identifying all product and effluent streams and utility consumptions. In addition to a definition of process operating conditions that would maximize liquid yield of the <190°C fraction, identification of secondary upgrading alternatives which would increase/maximize the liquid product yields was requested.

The developers were requested to comment on the operability of the coals in their raw state and to identify the extent of beneficiation required (e.g. reduction of ash content, increase of volatile matter, increase in reactive/inert content ratio), to maximize liquid yields by their process.

As the Prefeasibility Study progressed and the results of the B.C. Research and SBRG test programs indicated that the nominated B.C. coals were poor liquefaction candidates, follow up discussions were held with three of the process developers, HRI, NCB/BP and Veba Oel (German Process). These meetings led to the establishment of autoclave or extraction test programs with each of the process developers to better evaluate the coals under more optimum process conditions.

Based on the development stage and commercialization plans, and their predictions, an evaluation of the processes was performed as outlined in the following paragraphs.

3.2.2 H-Coal Process

During discussions with HRI, it became evident that they did not consider the SBRG test results to be truly representative of the H-Coal process. Even though they appreciated the extent of details of the SBRG procedure, the absence of a recycle coal-derived solvent and the inability to simulate an ebullated bed reactor were of major concern. In HRI's view, a true H-Coal process would be capable of producing higher yields than predicted by the SBRG results. It is recognized that the SBRG tests were not performed at optimized conditions.

HRI recognize that the B.C. coals are difficult to liquefy, as was evident from the comparison with Illinois No.6 test results. With maximum recycle of residual oils, higher reactor temperatures (450 to 460°C versus SBRG's temperature of 440°C) and increased catalyst activity, HRI predicted that 40 to 50% distillate oil yield should be achievable. However, they have no data on similar high rank coals to use as a basis for determining realistic distillate oil yields for the nominated B.C. coals. The highest rank coal processed to date by HRI in both autoclave and continuous bench scale test equipment is a German high volatile bituminous "A" coal.

However, it was decided that HRI commission a microautoclave test program to better evaluate the H-Coal process with respect to the nominated B.C. coals. Although HRI would have preferred to evaluate the B.C. coals following their standard autoclave and continuous bench scale testing procedures, they agreed to conduct microautoclave tests which HRI claimed were designed to improve upon the results of the SBRG test program and to project the estimated yields for the liquefaction of these coals by a representative H-Coal process.

HRI improvised a modification to their microautoclave test program to simulate coal-derived recycle solvent and recycle of vacuum bottoms. With their previous experience on similar coals in the bench and PDU scale tests, HRI were able to predict a yield of 43% for a continuous H-Coal process.

Since the initial slurrying solvent used was hydrogenated anthracene oil, a distribution of distillate oil fractions was predicted based on the behaviour of the anthracene oil during the reaction. The range of the distillate product yields estimated on an maf coal basis are:

Light Distillate	(IBP - 205°C)	1.8% - 3.7%
Middle Distillate	(205°C - 345°C)	5.8% - 19.9%
Heavy Distillate	(345°C - 525°C)	35.4% - 19.4%

Although the distillate oil yield is expected to be 43%, the distribution of the light, middle and heavy distillate fractions could be anywhere between the two extremes. Even then, most of the distillate oil is in the middle and heavy (205°C +) fractions.

The above predictions are based on previous experience with 'similar' coals and the concept of vacuum bottoms recycle. As mentioned earlier, the highest rank coal processed by HRI in both autoclave and continuous bench scale test equipment is a German high volatile bituminous "A" coal, which is lower in rank than the B.C. coals. Furthermore, the concept of vacuum bottoms recycle has yet to be demonstrated in continuous pilot scale equipment. Unless the vacuum bottoms recycle concept is successfully demonstrated on a larger scale, this process should be regarded as unproven for liquefying the B.C. coals.

The HRI test results are similar to the B.C. Research microautoclave test results, within acceptable experimental accuracy, and tend to substantiate the SBRG findings that the nominated B.C. coals are difficult to liquefy.

3.2.3 Ruhrkohle/Veba Process

After receiving the test data provided, the German response was somewhat guarded. Although, the B.C. coals would be liquefied by their process, the expected yields would be somewhat low.

To obtain a better understanding of the range of flexibility of the coal properties and get clarification on their guarded statements, discussions were held with Ruhrkohle and the Bergbau-Forschung Research personnel.

The relative low volatile content and high content of non-reactive matter of the B.C. coals were attributed to the prediction of the low distillate yields. This was evident from the B.C. Research microautoclave tests, when the yields of the B.C. coals were compared with Illinois No. 6 coal yields. In addition to the low volatile matter, a significantly important parameter, the B.C. coals possess high indices of reflectance of the vitrain content (in excess of 1.1). The German process is less suited for coals with reflectance indices in excess of 1.0.

Most of the German process data relate to reactor temperatures at 460°C and higher and with a coal-derived recycle solvent. The SBRG continuous tests were performed at 440°C with a solvent on a once through mode of operation. The process developers were asked to comment on the possibility of predicting the data at 440°C and the confidence thereof. They were unable to make any predictions due to unavailability of data at lower temperatures.

The limitations of the SBRG test results (lower reactor temperatures and absence of recycle solvent) were recognized. Under the conditions available, the SBRG projected yield of between 18% and 34% represented generally the typical yields that could be obtained from such coals with the use of a proper recycle solvent and higher reactor temperatures. Ruhrkohle speculated that, by reducing the mineral matter content of the coals to about 4% (their normal mode

of operation) the net distillate yields would be in the proximity of the maximum yield obtained by the SBRG tests. The speculated yield is based predominantly on the coal proximate analysis. However, definite yield data could be obtained by performing bench scale microautoclave tests followed by continuous tests in their 0.5 tonne/day process development unit at Bergbau-Forschung.

At a subsequent meeting with Veba Oel, it was decided to commission an autoclave test program to be performed by Veba, to better evaluate the German process with respect to the nominated B.C. coals. The tests are currently underway. However, the results will not be available in time to be incorporated in this report.

3.2.4 NCB/BP LSE Process

As the test programs conducted by B.C. Research and SBRG were not designed to 'simulate' the NCB/BP Liquid Solvent Extraction (LSE) process, discussions were held with the National Coal Board and subsequently with NCB and British Petroleum personnel to obtain information on the expected distillate yields from their process with the nominated B.C. coals and on possible advantages of the process. At the initial meeting between NCB and the Western Canada Coal Liquefaction Study Consortium, NCB volunteered to conduct extraction tests on samples of the Greenhills and Monkman coals and predict yield data and capital cost for a commerical plant.

NCB extracted the coals using hydrogenated anthracene oil and obtained 72 and 67 wt% on maf coal extraction for the Greenhills and Monkman coals, respectively.

Using this extraction data and the coal analysis as a data base, NCB were able to predict a 3.75 barrels of transportation fuels per tonne of maf Greenhills coal. NCB claim that their predictions were subsequently confirmed by conducting hydrocracking tests of the extract on their test unit. The extraction and hydrocracking results were not made available.

NCB assumed that some of the material in the extract would not be easily hydrocracked. Consequently, the configuration they adopted uses the high boiling oil fraction as fuel for both plant and power production. NCB also suggested that further improvement of liquid yields might be possible by coking this fraction where demand existed for high quality coke. However, Exxon's experience with Flexicoking suggests that this may not be a feasible option.

The NCB appeared to have no doubt that their LSE process could accommodate both Greenhills and Monkman coal. The high liquid yields, high quality products, low severity extraction and two stage operation are all attractive features of the process. However, the most limiting feature of this process (at least in comparison to the other processes under consideration) is that to date it has been demonstrated only on a semi-continuous unit with a coal capacity of 30 kg/hr. The next stage of development is to complete the engineering and construction of a 25 tonne per day pilot plant comprising solvent extraction, filtration and hydrocracking units. Once this integrated unit is completed, more data should be available for a better evaluation to be made of the process.

NCB claim that, because of the developed status of the extraction/filtration step and the straight-forward nature of the hydrocracking step, the LSE process is at a stage of development at least as advanced as competing direct liquefaction processes. This claim may be valid on a small scale. However, it should be noted that several of the liquefaction processes, currently being piloted at the 140-200 tonne per day scale, have encountered problems, not necessarily process-derived, that were not envisaged during the laboratory testing stage. Also, NCB/BP have yet to demonstrate an integrated plant on a large scale.

Finally, the success of the NCB/BP LSE process rests on a filtration step which is used to separate mineral matter and unreacted coal from the coal liquid extract. NCB claim that process conditions

have been optimized to ensure ease of filtration and this is in no way a difficult or expensive operation. However, this step should be demonstrated on a much larger scale and over a wide range of coals before total confidence can be placed in this process.

3.2.5 EDS Process

The initial response of Exxon, after reviewing the coal property data and the non-catalytic tubing bomb test data, was that the B.C. coals could be liquefied. The liquid yields, however, would be lower than for the lower rank coals more commonly processed, e.g. Illinois No. 6, Gulf Coast lignites, Wyoming coal, etc.

Discussions were held with Exxon pertaining to very low conversions for high rank Appalachian Coals which were reported in their literature. Exxon confirmed that low yields would be expected with high rank (medium and low volatile) coals. As volatile matter content is an important parameter in the EDS process, conversions of the B.C. coals, containing 25.5 and 26.8% volatile matter on a DMMF basis, are expected to be in the range of 20-25% only.

Exxon did stress that the test conditions used to develop the coal data bank and volatile matter versus liquid yield correlation were not optimum for high rank coals. As such, improved liquid yields would be expected if operating conditions were optimized. In addition, Exxon personnel predicted that improved yields would be experienced if residue recycle was incorporated into the process, a step that they are just beginning to develop.

In view of the undefined commercialization plans and prediction of low liquid yields, the EDS process is not recommended for liquefying the B.C. Coals.

3.2.6 SRC II Process

SRC International were contacted for information pertaining to the SRC II process and the expected yields with high rank coals. No response was received -- a further indication that there is no commitment for continued development of the SRC II process since cancellation of the 5 400 tonne per day demonstration plant program late in 1981. In fact the Fort Lewis 45 tonne per day pilot plant is no longer in operation and is reported to be in the process of being dismantled.

Thus, no further evaluation of the SRC II process is recommended.

3.3 PROCESS EVALUATION

3.3.1 General

Because of the prediction of low distillate yields (between 19% and 34%) from the SBRG test, the validity of any further evaluation of the coal liquefaction program was questioned. However, in subsequent disucssions with NCB/BP, HRI and Veba Oel, the process developers assured at least a 40% distillate yield. The confidence in the process developers assurance was partially substantiated by the B.C. Research microautoclave test results which predicted distillate yields between 42% and 50% in one set of results. Furthermore, the SBRG test was performed at one set of predetermined conditions, while the B.C. Research microautoclave tests indicate increased yields with increasing reactor temperature (higher than could be achieved in the SBRG equipment).

Although the microautoclave tests predict the distillate yield, they do not define the split between the naphtha, middle distillate and heavy distillate fractions. To obtain the actual distillate yield and the percentage split of the distillate fractions, further continuous testing would have to be conducted. Time and budget limitations did not permit this extensive testing.

To test the economics of a direct liquefaction process, it was agreed to perform a detailed evaluation with a specific coal and a specific process. The coal selected was from the Greenhills mine since this coal had demonstrated marginally better liquefaction potential in the coal testing program. This coal selection does not indicate that possible use of the Monkman coal has been rejected -- further testing must be conducted before a final coal selection can be made. Although any of the three considered processes (H-Coal, Ruhrkohle/Veba or NCB/BP LSE) could have been selected to represent a direct liquefaction plant economics, the H-Coal process was chosen. This decision was made because better in-house information existed on this process. It should be emphasized that the choice of the H-Coal process does not imply that it has any technical and/or economic advantages over the other direct liquefaction processes (Ruhrkohle/Veba or NCB/BP LSE). The selection of this process was made to expedite the prefeasibility study.

A 40% net distillate yield was selected as being representative of the conventional configuration for the H-Coal process feeding Greenhills coal. The evaluation was conducted on the basis of processing Greenhills coal with the exception of the assumed split between naphtha, middle distillate and heavy distillate fractions and the assumed analyses of the raw liquid product fractions. The split between the three liquid fractions was prorated from HRI data on Illinois No. 6 coal to give a net 40% distillate yield and the elemental analyses of the raw products were assumed to be the same as for Illinois No. 6 coal as no data existed for Greenhills coal.

3.3.2 H-Coal Base Case Configuration - 40% Distillate Yield

The Base Case configuration of the H-Coal liquefaction plant is designed to be energy self sufficient. While no energy is imported, 40% distillate yield on maf coal basis is obtained. With the coal feed as the only form of energy, the residue and fuel gas produced in the liquefaction process are used in the complex to fulfill the energy needs.

With the relatively low distillate yield, substantial quantity of residue is formed. Most of the residue is gasified to produce hydrogen. A portion of this hydrogen is used in the liquefaction stage, and the remainder is utilized in upgrading the products. In addition to hydrogen production, power as required, is generated by combustion of the residue. The excess residue is disposed of in an environmentally acceptable manner.

The liquefaction plant also produces significant quantities of fuel gas. Besides the fired heaters and other uses, the fuel gas is used to drive the gas turbines in the air separation plant - a very large gas consumer. The exhaust gases from the air separation compressor turbine drivers possess a high energy value, which is used to generate make-up steam. The excess fuel gas is exported from the liquefaction complex.

A conceptual H-Coal Base Case plant complex is shown in Figure 3.1.

Development of this Base Case defined the quantities of intermediates and products. This enabled the various alternative processing configurations to be selected, any of which could possibly offer improved economics. Five alternative processing schemes were then developed to a stage sufficient to produce preliminary comparative economics for each. The key features of the process option configurations are listed in Table 3.1. Table 3.2 presents the raw materials used and products formed from each of the process options. The alternate process configurations are described below.

3.3.3 Case 1 - H-Coal Configuration with 50% Distillate Yield

With the increased distillate yield, a lesser amount of residue is produced. With the increased distillate yield the hydrogen requirement for both the coal conversion and product upgrading is also increased.

Gasification of the residue produces all the hydrogen needs for the plant. In the Base Case, power was generated by combustion of the residue (beyond the hydrogen needs), and the fuel gas was used to fulfill the oxygen plant needs while exporting the excess. In this process option, the oxygen plants needs and the incidental process requirements are fulfilled by the fuel gas. Sufficient fuel gas is available to generate power for the plant requirements.

Hence, this option is energy self sufficient.

3.3.4 Case 2 - 40% Distillate Yield, Residue Gasification and Partial Oxidation of Fuel Gas

In this option, all the residue produced is gasified to form a synthesis gas and finally hydrogen. All the fuel gas produced in the liquefaction process is also converted to syngas via partial oxidation.

The syngas from the gasified residue contains H_2 and CO in a 1:1 ratio. A slip stream of this gas, after a small dedicated acid gas removal unit, is fed to the Mobil Methanol to Gasoline (MTG) complex, as described below. The bulk sour gas stream undergoes shifting for maximum H_2 production. After sweetening and purification, high purity hydrogen is utilized in the liquefaction unit and the product upgrading facility. Excess hydrogen is fed to the MTG complex to adjust the H_2/CO ratio.

All the fuel gas produced in the liquefaction process and the MTG plant is fed to a partial oxidation unit. Here the hydrocarbon gases react with the oxygen and steam and are partially oxidized to produce a syngas in the H_2/CO ratio of about 1.5:1. This syngas is mixed with the high purity hydrogen stream and the sweetened slip stream from the residue gasification in an appropriate proportion to obtain a 2.2:1 H_2 to CO ratio as feed to the MTG complex. In the Mobil MTG process, syngas is converted to gasoline blendstock via the route syngas-methanol-gasoline, using Mobil proprietary technology.

Since all the residue is gasified, electricity has to be imported to meet the needs of the plant. Also the compressors in the air separation plant have to be driven with imported power. However, the steam requirement within the complex is generated from the partial oxidation plant. The combustion gases from the partial oxidation plant do not contain any solids, therefore, do not require quenching. The gas contains sufficient heat to produce make-up steam for the complex.

3.3.5 Case 3 - 40% Distillate Yield, Gasification of Residue and Coal Beneficiation Rejects and Partial Oxidation of Fuel Gas

This process option is similar to Case 2 except that, along with the residue, the tailings from the coal beneficiation plant are included for gasification. Hence, the gasifier capacity and throughput is increased.

The material balance around the syngas is adjusted to obtain a 2.2:1 H_2/CO ratio prior to feeding the Mobil MTG facility as described in Section 3.3.4

This option increases the "feed" to the syngas production and hence increases the blended gasoline product from the MTG plant. In this option, power is imported to compensate for the residue and fuel gas utilization for increased product yields.

3.3.6 Case 4 - 40% Distillate Yield, Hydrogen Production via Steam Reforming of Natural Gas and Gasification of Residue and Coal Beneficiation Rejects for Production of Gasoline Blendstock

In this process option, all the residue from the liquefaction process and the coal beneficiation rejects is gasified and shifted to a 2.2:1 H_2/CO ratio. After acid gas removal, the syngas is fed to a Mobil MTG plant for the production of gasoline blendstock.

The major difference in this configuration is the hydrogen production plant. Hydrogen for the coal conversion unit and the hydrogen requirement for the upgrading of the liquid products is produced by

reforming imported natural gas. The fuel gas requirements for the steam reformer are partially met by the fuel gas produced in the liquefaction and the MTG plant. The deficiency is met by imported natural gas.

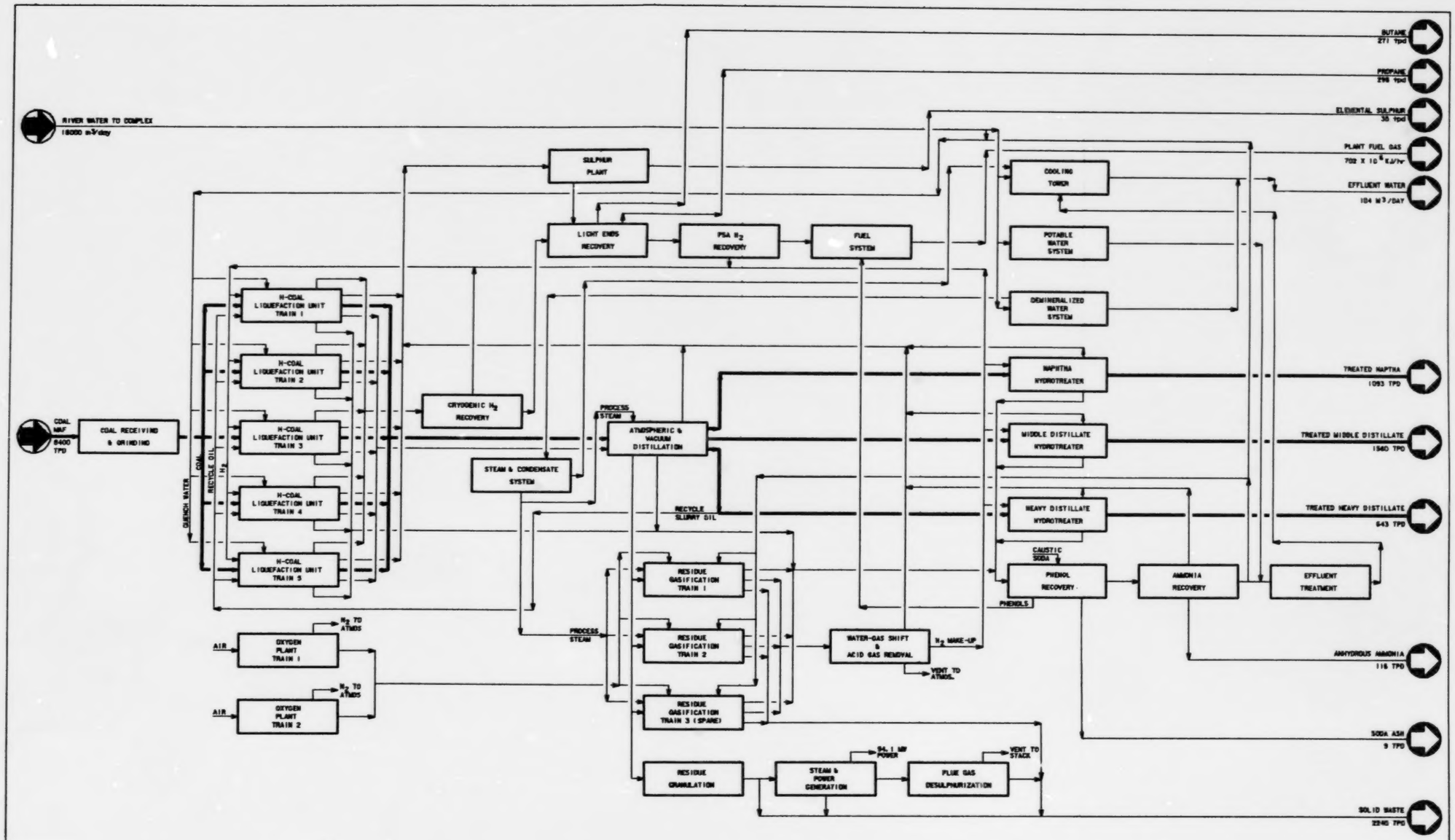
The power requirement for the liquefaction complex is met by importing electricity.

3.3.7 Case 5 - 40% Distillate Yield and Hydrogen Production via Steam Reforming of Natural Gas

In this option, hydrogen is produced by steam reforming of imported natural gas. The fuel requirements for the steam reformer are partially met by the fuel gas produced by the liquefaction plant. The difference is met by imported natural gas.

The fuel requirement for the fired heaters and other users in the liquefaction plant is fulfilled by part of the fuel gas produced within the complex. The excess fuel gas is used in the steam reformer for hydrogen production, as noted above.

Steam and power for the plant needs are generated by combusting part of the residue from the coal liquefaction process. The excess residue is disposed of at zero value or zero disposal cost. (It is assumed that an environmentally acceptable use can be found for this material under these conditions -- i.e. power generation excess to the needs of the liquefaction facility).



Western Canada Coal Liquefaction Study
Prefeasibility Study
Simplified Block Flow Diagram
H-Coal - Plant Configuration

TABLE 3.1

PROCESS OPTION CONFIGURATION

	Base Case	Case 1	Case 2	Case 3	Case 4	Case 5
Residue	To H_2 Production To Power Plant To Disposal *	To H_2 Production	To H_2 Production To Methanol Conversion	To H_2 Production To Methanol Conversion	To Methanol Conversion To Disposal *	To Power Plant
Coal Rejects	-	-	-	To H_2 Production To Methanol Conversion	To Methanol Conversion	-
Excess Fuel Gas	To O_2 Plant To Export	To O_2 Plant To Power Plant	To Partial Oxidation -	To Partial Oxidation -	To Steam Reformer as Fuel Gas To O_2 Plant	To Steam Reformer as Fuel Gas
Natural Gas	-	-	-	-	To H_2 Production To Fuel Gas Make-up	To H_2 Production To Fuel Gas Make-up
Power	From Power Plant	From Power Plant	Import	Import	Import	From Power Plant

* Residue disposal in an environmentally acceptable manner.

TABLE 3.2

RAW MATERIALS AND PRODUCTS

	Base Case	Case 1	Case 2	Case 3	Case 4	Case 5
Raw Materials						
Coal MAF (T/D)	8 400	8 400	8 400	8 400	8 400	8 400
Tailings MAF (T/D)	-	-	-	800	800	-
Natural Gas ($KJ \times 10^6$ per day)	-	-	-	-	69 784	69 784
Utilities (Import)						
Power (MW)	-	-	237	307	155	-
Fuel Gas ($KJ \times 10^6$ per day)	-	-	-	-	28 018	14 113
Products (T/D)						
Naphtha	1 093	1 279	1 093	1 093	1 093	1 093
Middle Distillate	1 560	1 819	1 560	1 560	1 560	1 560
Heavy Distillate	643	797	643	643	643	643
Propane	298	298	335	348	373	298
Butane	271	271	335	359	407	271
Gasoline Blendstock	-	-	966	1 201	2 008	-
Fuel Gas ($KJ \times 10^6$ per day)	17 160	-	-	-	-	-

3.4 SITE CONSIDERATIONS

As Greenhills coal was chosen as the reference coal, a plant site adjacent to the Greenhills mine in south-eastern British Columbia was selected. The precise location of the site however will be contingent on the local topography so as to minimize site preparation requirements. A primary reason for considering a site adjacent to the mine is the delivery of beneficiated coal by belt conveyor thus avoiding the cost of rail shipment. Estimated size of the proposed complex is 120 hectares, consisting of 30 hectares for process units, 20 hectares for effluent and fire water ponds and 70 hectares for coal receiving, offsites and utilities.

Rail service is available to the Greenhills mine which could be extended to provide product loadout facilities for the complex. However, the suitability of this line for the shipment of large tonnage equipment for the complex is uncertain. All-weather road access to the plant site is also available.

Raw water is available in part from wells on the mine property and the remainder from the Elk River. Power is available in the Greenhills area but is limited. Therefore it is intended that only emergency power be drawn from this line. Larger power requirements will require a new 230 kV line. Excess fuel gas produced by the complex will be transported by pipeline for consumption at the mine or local industry. Should natural gas be required, a pipeline would be provided from the Columbia Natural Gas pipeline located 20 km south of the proposed site.

The support facilities relating to the complex include coal receiving and storage, steam and power generation and all necessary offsite and utility facilities to service the process units. These facilities include air, water and solid waste pollution control systems and service systems such as catalyst and chemical storage, product tankage and loadout, steam and condensate distribution, cooling water, BFW and water treatment systems.

In-plant coal storage is provided by two 75 000 tonne coal piles providing 15 days storage at full production capacity. In addition, a 10 000 tonne emergency pile is provided for plant startup and shutdown. Residue to be used as Steam Plant fuel is stored in a 10 000 tonne storage pile.

The Steam and Power Generation Unit will combust residue to partially supply the steam requirements for in-plant power generation. Remaining steam will be provided by steam generators in the Process Units. The steam turbine generator rated at 94.1 MW will consist of a three stage turbine linked to a DC exciter to produce 13.8 KV power for in-plant use.

Liquid tankage is provided for plant startup, plant upset conditions, 4 days stabilized product storage and 30 days finished product storage of naphtha, distillates, and by-products. Loadout facilities are provided for rail shipment of all finished products.

3.5 SOCIO-ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS

3.5.1 Socio-Economic Considerations

The Regional District of East Kootenay covers the south east corner of the Province of British Columbia with the project area located within the Elk Valley sub-region which contains the City of Fernie, the District of Sparwood and the Village of Elkford.

The Region's population in 1979 was estimated at 50 000 and is to grow to 110 000 by 1990 with 35% of this total in the Elk-Valley sub-region. The estimated manpower force for 1979 in the Region is 25 000.

The industries in the Region include coal mining, mining of various minerals, forestry and tourism. The existing coal deposits are large enough to be of national significance and are found along the western slopes of the Elk Range in the Rocky Mountains and all along the eastern side of the Lower Elk Valley.

There is an established community and services infrastructure existing in the Region with the main services concentrated in Cranbrook. The Region has an airport and is served by highways and railroads. The immediate development prospects are in the Elk Valley and Columbia Valley sub-regions stimulated by coal mining and tourism respectively. This growth has already been anticipated to some extent but many local infrastructure services need to be expanded to accommodate this growth.

The proposed coal liquefaction project will generate a number of benefits including a reduction in unemployment, promotion of training policies for labour skills in short supply and stimulation of the local economy as a result of project requirements for equipment and materials. The community services and infrastructure local to Elkford would be significantly expanded by the project.

The coal liquefaction facility will take 3-4 years to construct and will require a 5 000 peak labour force with an operating labour force of 1 000 workers. Labour availability in Western Canada will be dictated by the timing of the planned mega-projects in Western Canada and a detailed study of the timing of these projects will be required to evaluate their effect on the availability of labour for this project.

During the construction phase this project will generate 13 000 direct and indirect jobs. During the operation phase the project will create approximately 4 000 employment opportunities. Accommodation for construction personnel will likely be in the form of construction camps. However, it is predicted that the operating phase will result in an influx of 3 500 people to Elkford around 1990. The predicted population for Elkford in 1985 is 7 500 and in 1990 is 11 000. Therefore, this increase should only involve expansion of the planned service base to accommodate the projected increases. These requirements such as accommodation, education, health and municipal services will require advance planning in order that the services are available upon the arrival of the additional people.

3.5.2 Environmental Considerations

It is assumed that the coal liquefaction complex is located at the Greenhills Mine site, which is committed to industrial development use. While the exact complex location is not known and the site specific environmental data are not fully available at present, based on a general appreciation of the project area, it appears that the coal liquefaction project does not generate any unresolvable impacts on the environment.

The likely environmental impacts can be categorized into three types: short-term impacts primarily occuring during the construction phase, long-term impacts usually associated with the operation phase, and residual impacts indefinitely remaining after the plant decommissioning.

In consideration of these potential impacts, appropriate mitigation measures are proposed for the construction, operation and post-operation phases of the project. These include: construction monitoring, erosion/siltation control, site drainage control, wastewater treatment, air emissions control, solid wastes management, incineration, re-vegetation and slope stabilization.

The environmental control measures are designed on the basis of best available control technology to ensure the applicable British Columbia regulatory criteria are satisfied. With the implementation of these measures, no significant impacts are anticipated on the water quality, air quality, vegetation, wildlife, aquatic life, soils, topography and land use. In addition, necessary in-plant health and safety protection measures to be incorporated into the engineering design would ensure a satisfactory working environment for the plant workers.

A major impact may result from the drawing of process make-up water from either the Elk River, Fording River, or wells. In the detailed

engineering phase, considerations should be given to withdrawal of the raw water from a combination of these sources or nearby lakes, and/or to maximize the re-use of process wastewater by treating and re-use of the cooling water blowdown and the neutralized boiler feedwater plant effluent.

It must be noted, however, that site specific field investigations have not been undertaken and data are not available during this Phase I study. In the future Phase II work, some assumptions and sequential observations made in the present environmental overview will have to be investigated and verified. A more definitive environmental evaluation can then be carried out to determine quantitatively the effects of the coal liquefaction project on the environment.

4.0 PRELIMINARY ECONOMIC ANALYSIS

Estimated capital costs, annual operating costs and product revenues are outlined below for the 'typical' H-Coal Base Case and five Alternative Cases selected to evaluate the sensitivity of the preliminary project economic analysis to changed modes of operation. Capital and operating costs are in 1982 Canadian dollars; operating costs and product revenues are based on 310 days per year operation. Product prices are estimated on the basis of the January 1982 new oil price provided by the September 1981 Oil Pricing Agreement and, alternatively, on the basis of the April 13, 1982 Announcement by the Province of Alberta.

4.1 SUMMARY

Capital cost estimates were prepared for the Base Case and five Alternative Cases as follows:

Base Case: Incorporating all facilities described in the Technical volume of this report to produce a nominal 24 000 barrels per day of syncrude. Solid residue is used to generate hydrogen and inplant power. Excess residue is discarded at an assumed disposal cost of $10.00 per tonne.

Cost $2.02 Billion.

Alternative Cases

Case 1: Incorporating all Base Case facilities described above to give an assumed 50 percent distillate yield from the liquefaction unit and a nominal 28 500 barrels per day of syncrude.

Cost $2.062 Billion

Case 2: Base Case process facilities with no power generation. Excess residue and fuel gas are gasified and converted via the MTG process to finished gasoline. Electrical power is purchased. Plant capacity is a nominal 24 000 barrels per day syncrude and 8 000 barrels per day gasoline.

Cost $2.520 Billion.

Case 3: Base Case process facilities with no power generation. Coal tailings, excess residue and fuel gas are gasified and converted via the MTG process to finished gasoline. Electrical power is purchased. Plant capacity is a nominal 24 000 barrels per day syncrude and 10 000 barrels per day gasoline.

Cost $2.630 Billion.

Case 4: Base Case process facilities with no power generation. Hydrogen make-up is by steam-methane reforming. Excess residue is gasified and converted via the MTG process to finished gasoline. Electrical power is purchased. Plant capacity is a nominal 24 000 barrels per day syncrude and 17 000 barrels per day gasoline.

Cost $3.039 Billion.

Case 5: Base Case process facilities with inplant power generation. Hydrogen make-up is by steam-methane reforming. Excess residue, not used for inplant steam and power generation, is discarded at zero value or zero disposal cost (on the assumption that it can be utilized elsewhere as boiler fuel or some other type of fuel). Plant capacity is a nominal 24 000 barrels per day syncrude.

Cost $2.087 Billion.

Operating cost estimates were developed for the Base Case and five alternatives. Operating costs calculated in 1982 dollars were based on:

- coal requirements at $80.00 per tonne
- raw material requirements
- utility requirements (alternative cases only)
- manpower estimates for complex staff
- maintenance parts
- taxes and insurance.

Product revenues were also developed for the base case and alternatives, in 1982 dollars, based on the September 1981 Oil Pricing Agreement. Criteria for product revenues were:

- syncrude based on September 1981 Oil Pricing Agreement
- propane based on September 1981 Oil Pricing Agreement
- butane based on September 1981 Oil Pricing Agreement
- gasoline based on September 1981 Oil Pricing Agreement
- sulphur based on prevailing product prices
- ammonia based on prevailing product prices
- soda ash based on prevailing product prices.

A summary of annual revenue and operating costs in 1982 dollars follows.

	Revenue	$1 000 Operating Cost	Gross Margin
Base Case	437 500	393 080	44 420
Alternative Cases			
Case 1	494 050	391 725	102 325
Case 2	562 710	452 670	110 040
Case 3	599 180	472 440	126 740
Case 4	677 870	584 640	93 230
Case 5	420 113	494 050	Negative

The economic analysis is based upon 100 percent equity financing. Capital expenditures are spread over a seven year period with a three year startup and commissioning period prior to attaining design capacity. Working capital, escalation, capital cost allowances and investment tax credits have been considered in developing the cash flow model.

Using the cash flow model, the DCF rate of return for the Base Case and alternatives is as follows:

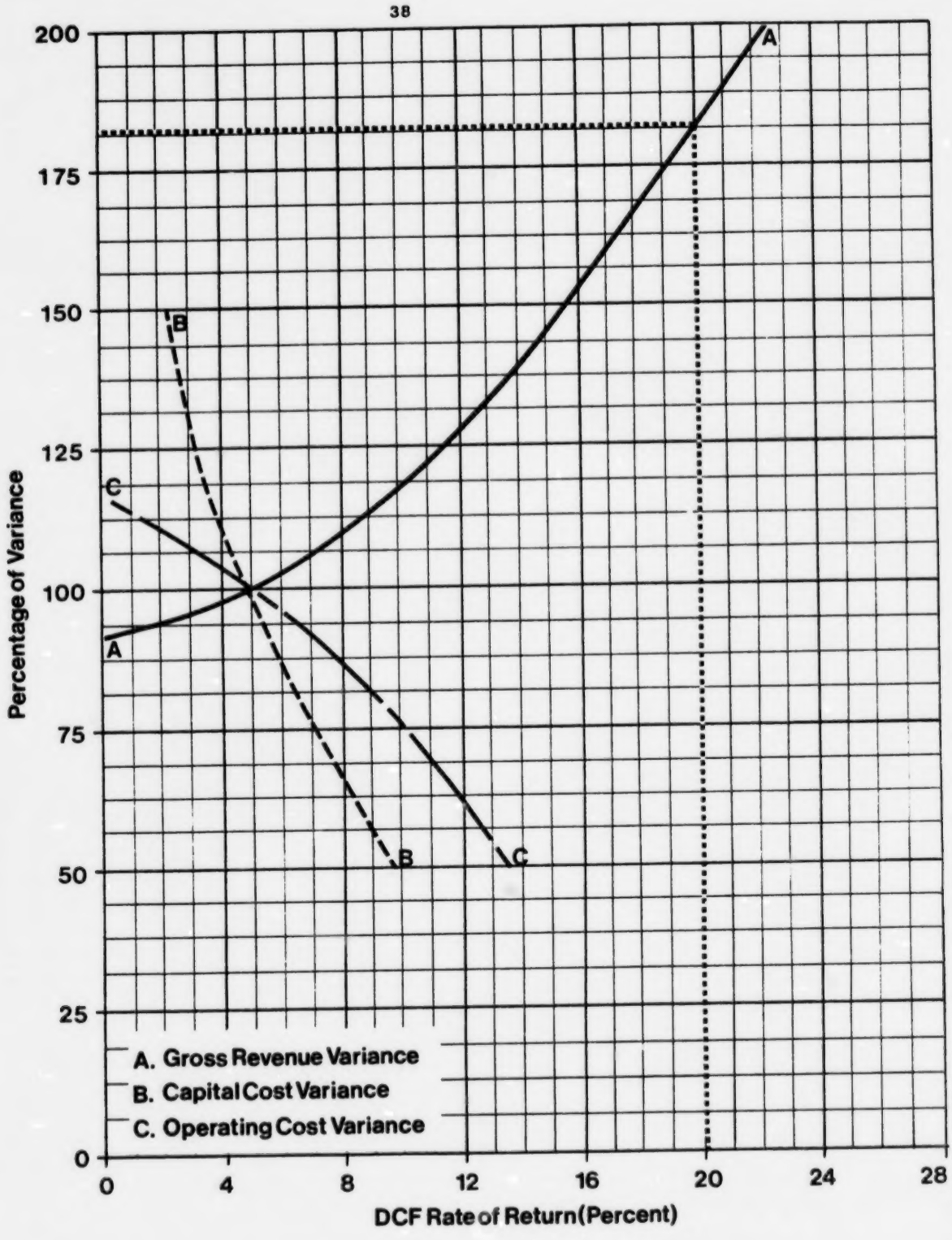
SEPTEMBER 1981 OIL PRICING AGREEMENT

	DCF rate of return (percent)	
	$80/tonne coal	$50/tonne coal
Base Case	4.6	10.2
Alternative Cases		
Case 1	8.4	12.7 (Cal.)
Case 2	7.6	
Case 3	8.1	
Case 4	7.7	
Case 5	Negative	

Sensitivity analyses were run on the Base Case at two coal prices to test the effect of variations of capital cost, product revenue and operating cost on the DCF rate of return. Figures 4.1, 4.2 and 4.3 summarize the results of these sensitivity analyses.

Three special sensitivity analysis cases were run, as summarized below with their respective DCF rates of return:

	DCF rate of return (percent)
Base Case with corporate tax calculation, rather than single project basis	6.6
Base Case with $10.00 per barrel syncrude discount	Negative
Base Case with $60.00 per tonne coal, $5.00 per barrel syncrude discount and adjusted escalation factors	9.6



Effect of Gross Revenue, Capital Cost & Operating Cost Variances on Base Case DCF Rate of Return ($80.00/tonne Coal)
Figure 4.1

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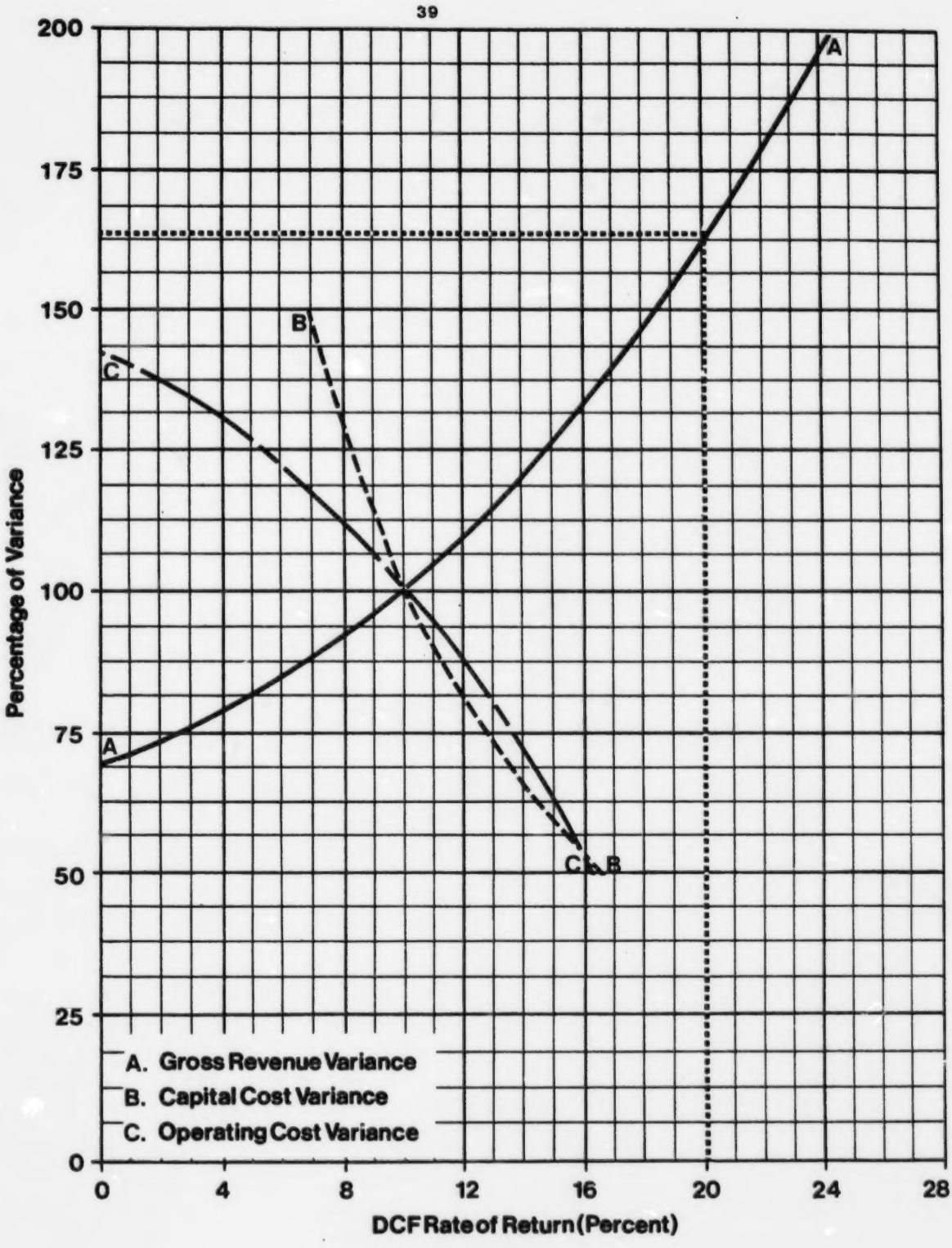
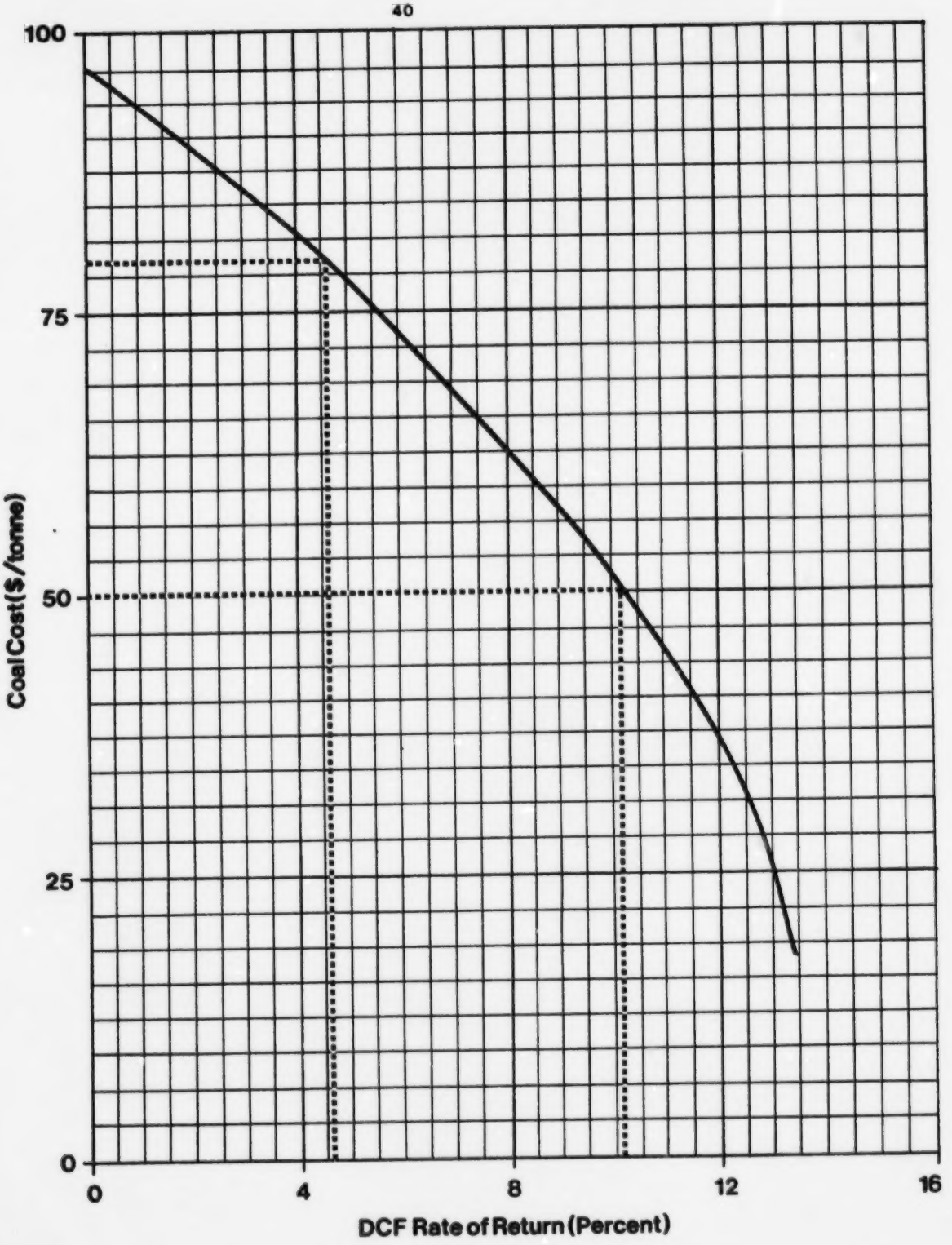


Effect of Gross Revenue, Capital Cost & Operating Cost Variances on Base Case DCF Rate of Return ($50.00/tonne Coal)
Figure 4.2



Effect of Coal Cost on Base Case DCF Rate of Return
Figure 4.3

As an addendum to the economic analysis, project DCF rates of return were calculated for the Base Case and Alternative Cases 1 - 5 based on the recent April 13, 1982 Announcement by the Province of Alberta, in which a revised forecast of new oil reference prices was presented to reflect recent changes in projected World Oil prices. Based on this Announcement, the H-Coal syncrude price was calculated to be $56.85 per barrel effective July 1986, compared to $72.40 per barrel using the September 1981 Agreement pricing structure.

Project DCF rates of return are as follows for the Base Case and Alternatives, at the two coal prices:

APRIL 13, 1982 PROVINCE OF ALBERTA ANNOUNCEMENT

	DCF rate of return (percent)	
	$80/tonne coal	$50/tonne coal
Base Case	Negative	4.3
Alternative Cases		
Case 1	0.0	7.7
Case 2	Negative	6.1
Case 3	Negative	6.4
Case 4	Negative	4.8
Case 5	Negative	Negative

This analysis clearly indicates that the effect of the lower product prices is to reduce DCF rates of return substantially at equivalent coal prices. In fact, indicated DCF's are negative or zero for $80.00 per tonne coal and coal prices must be reduced by $30.00-$40.00 per tonne to achieve DCF rates of return similar to those obtained in the original analysis with the lower product prices.

4.2 BASIS FOR ECONOMIC EVALUATION

Capital cost estimates are provided for six cases, a Base Case and five alternative cases. All costs are provided in first quarter 1982 Canadian dollars.

The Base Case capital cost estimate is based on cost data developed for each process unit, offsite facilities and utility systems. Included in the process units and offsite facilities are proprietary and non-proprietary processes. Cost information from process vendors was used in developing process equipment direct costs for the following process packages:

- Naphtha Hydrotreating
- Middle Distillate Hydrotreating
- Heavy Distillate Hydrotreating
- Cryogenic & Pressure Swing Adsorption Hydrogen Recovery
- Stretford Sulphur Plant
- Steam Generation
- Power Generation
- Flue Gas Desulphurization
- Phenol Recovery
- Ammonia Recovery.

Economic data for the above process packages were provided in U.S. dollars, Gulf Coast location. These data were converted to Canadian dollars, Greenhills location by Kilborn.

A 25 percent contingency was used in the preparation of the capital cost estimate. This contingency is actually an average based on the degree of process uncertainty and the degree of project uncertainty in the cost estimates of the individual plant units. The process and project contingencies used to develop the average contingency are listed below.

Area		Contingency	
		Process	Project
200	Coal Preparation & Handling	Nil	20
300	Coal Liquefaction	15	20
400	Atmospheric & Vacuum Distillation	5	20
500	Naphtha Hydrotreating	10	20
600	Middle Distillate Hydrotreating	10	20
700	Heavy Distillate Hydrotreating	10	20
800	Light Ends Recovery	Nil	20
900	Hydrogen Plant	5	20
1000	Oxygen Plant	Nil	20
1100	Sulphur Plant	Nil	20
1200	Steam & Power Generation	Nil	10
1300	Phenol Recovery	Nil	20
1400	Ammonia Recovery	Nil	20
1500	Offsites	Nil	20
1600	Utilities	Nil	20

The Kilborn capital cost estimate represents an accuracy of plus or minus 30 percent or one chance in three that the actual plant cost will exceed the estimated cost by greater than 10 percent. No allowance has been made for "outside battery limits" infrastructure costs that could conceivably add to the overall project cost. These excluded infrastructure costs include such items as:

- housing and community services for permanent operating staff
- power transmission to the site (alternative cases)
- coal receiving facilities beyond the plant battery limits
- disposal of residue and ash from the site
- land costs and other miscellaneous owner's costs.
- natural gas transmission to the site (alternative cases)

Operating cost estimates were prepared for six cases (a Base Case and five alternative cases), based on an operating year of 310 days and consists of direct production costs (raw materials, manpower, utilities and maintenance) and fixed overhead charges (local taxes and insurance). All costs are provided in first quarter 1982 Canadian dollars.

Overall manpower for the Base Case complex is 860, based on the operating staff plan as given in Volume I of this report. Current labour rates for western operating facilities are $12.34 per hour for labourers and $15.95 per hour for tradesmen excluding all fringe benefits or a weighted average of $13.54 per hour. Fringe benefits were estimated to be 35 percent of the base rate resulting in a final wage rate of $18.28 per hour or $38 000 per year.

Coal mined at the adjacent mine at a strip ratio of 10:1 is beneficiated to reduce the ash and water content. Beneficiated coal is valued at $80.00 per tonne.

The Base Case complex is self-sufficient in electrical power and fuel gas and pumps its own water for internal use. However, electrical power and natural gas are required in selected alternative cases. In this cases the cost of electrical power and natural gas is determined using a cost per unit basis as follows:

Electricity	$ 0.0226 per kilowatt hour
Natural gas	$ 0.149 per normal cubic metre

Catalyst and chemical quantities and costs are based on process licensor information and current Canadian chemical prices. Coal liquefaction catalyst consumption is estimated to be three times greater than typical consumption rates for Illinois No. 6 coal.

Parts required for maintenance are estimated at one percent of the total plant cost while maintenance labour costs are included in the overall plant manpower staffing. An allowance of $2 000 000 per year has been provided for emergency subcontracted maintenance.

Local taxes and insurance are estimated to be two percent of the total plant cost plus working capital per year.

Liquid hydrocarbon pricing for the coal liquefaction complex is based on the September 1981 Oil Pricing Agreement wherein a new oil reference price of $45.90 per barrel was established, effective January 1982. H-COAL naphtha, middle distillate and heavy distillate is blended as a synthetic crude for transportation and pricing purposes. This syncrude is priced according to the new oil reference price of $45.90 per barrel less a hydrogen deficiency penalty of $3.00 per barrel. The hydrogen deficiency penalty represents an estimated cost of $1.00 per 1 000 standard cubic feet of hydrogen required to upgrade H-COAL syncrude to an oil sands quality syncrude.

Stabilized gasoline produced in Alternative Cases 2, 3 and 4 is valued at $50.00 per barrel as of January 1982. Cognizance of the finished quality of this product relative to syncrude was taken when establishing a price. Propane and butane as LPG was valued at $42.00 per barrel based on their energy content relative to other finished products.

By-products from the complex, including elemental sulphur, anhydrous ammonia and 57% wt soda ash, were priced at current 1982 values of $100.00 per tonne, $260.00 per tonne and $65.00 per tonne, respectively.

In 1st quarter 1982 dollar product prices for the coal liquefaction complex, based on the September 1981 Oil Pricing Agreement, are:

Propane	$42.00 per barrel	or $264.20 per cubic metre
Butane	$42.00 per barrel	or $264.20 per cubic metre
Stabilized Gasoline	$50.00 per barrel	or $314.50 per cubic metre
Syncrude	$42.90 per barrel	or $269.80 per cubic metre
Sulphur	$100.00 per tonne	
Ammonia	$260.00 per tonne	
Soda Ash	$65.00 per tonne	

For the economic analysis provided in the addendum, product prices are based on the recent April 13, 1982 Announcement by the Province of Alberta, in which a revised forecast of New Oil reference prices was presented to reflect recent changes in projected World Oil prices. Based on this Announcement, the H-Coal syncrude price was calculated to be $56.85 per barrel effective July 1986, compared to $72.40 per barrel using the September 1981 Agreement pricing structure. Prices for propane, butane and stabilized gasoline were prorated according to the new pricing forecast.

The economic and sensitivity analysis for the coal liquefaction complex was prepared to determine the economic feasibility of the project and to study various plant configurations. The economic model is a cash flow generator for before and after tax calculations. Developed within this model are certain assumptions used for this analysis.

This project has been evaluated to a January 1, 1982 reference date and assumes a 27 year project life. After a three year period for detailed feasibility studies and PDU coal testing, a four year construction period is scheduled followed by a 20 year production profile.

Capital costs as estimated in 1982 dollars were distributed by percentage to the year of construction and escalated to the appropriate year. The schedule for capital expenditures is as follows:

Year	Percent Capital	Percent Completion
1982	Nil	Nil
1983	Nil	Nil
1984	5	5
1985	15	20
1986	25	45
1987	30	75
1988	25	100

Plant production is expected to be phased in during the initial three years of operation, starting in 1989. Plant capacity in the first year of operation is expected to be about 40 percent with the commissioning of three of the five H-Coal liquefaction trains. Plant capacity is increased in the second and third years of operation to 70 and 90 percent of design capacity with the commissioning of the fourth and fifth H-Coal trains. Full capacity is attained in the fourth year of operations and maintained for the duration of the plant life.

5.0 RECOMMENDATIONS

For British Columbia to become less dependent on extra-provincial supply sources for its oil requirements, it is essential that alternate sources of energy be developed within the province. One possibility to simultaneously develop provincial resources and reduce dependence on outside sources of oil would be the development of coal liquefaction technology -- to produce high quality syncrude (or possibly finished petroleum products) from local coal resources. In view of this possibility, development of coal liquefaction technology should be continued with a view to commercialization by the late 1980's or early 1990's.

As it was not possible to make a final selection of the process and coal best suited for liquefaction, further testing is required before final selection can be made. The purpose of the technical and economic evaluation of the H-Coal process, as being 'typical' of the H-Coal, Ruhrkohle/Veba and NCB/BP processes, was to determine if further testing is warranted in view of the low distillate yields that were predicted by the microautoclave and continuous bench scale experimental programs.

As the results of the preliminary economic evaluation are discouraging, particularly with reference to the significantly lower New Oil price forecasts contained in the Province of Alberta Announcement of April 13, 1982, further development of the coal liquefaction project should be approached with caution. Further development is warranted to answer major unknowns identified in this prefeasibility study as the possible social benefits associated with the project are as important as, if not more important than, the financial benefits.

The main emphasis of the recommended development program should be placed on the evaluation of process parameters that would make the project more attractive economically, including the following:

- increased liquid distillate yield (above 40 percent) per tonne of feed coal,

- lower coal price and/or alternate source of coal that offers a better potential for liquefaction (lower rank than the Greenhills or Monkman coals) at low cost.

Specifically, it is recommended that a phased development program be undertaken that will ultimately lead to the completion of a detailed feasibility study only if results of the earlier tasks warrant continuation of the project.

5.1 EVALUATION OF OTHER COALS

As the economic attractiveness of the proposed coal liquefaction process is extremely sensitive to product revenue (one factor of which is distillate oil yield per tonne of coal) and to the price of coal, it is recommended that alternate B.C. coals be investigated for use as liquefaction plant feed. Key factors to use in this investigation are:

- adequate reserves to support the coal liquefaction project over a 20 year life, approximately 80-100 million tonne for a 10 000 tonne per day facility,

- low price, $50 per tonne or lower for beneficiated coal (6-8 percent moisture, 8 or less percent ash),

- good liquefaction potential, as indicated by the rank of the coal. In general, high volatile "A" bituminous, or lower rank, coals are more reactive than medium or low volatile bituminous coals.

If suitable other B.C. coals are found, a microautoclave program similar to the B.C. Research program conducted as part of this study should be commissioned to determine the reactivity of these coals relative to Greenhills and Monkman coals. Results of this test program would form the basis for the selection of the coal for subsequent testing by the process developers.

5.2 DISCUSSIONS WITH PROCESS DEVELOPERS

Discussions should be initiated with the three leading process developers (HRI, Veba Oel, NCB/BP) to better assess the capability of each process to efficiently convert the nominated B.C. coal to prime liquid transportation fuels. Important issues to be addressed during these discussions include:

- the degree of confidence demonstrated by the process developer in the ability of his process to give distillate yields in excess of 40 percent with Greenhills, Monkman or other nominated B.C. coal,
- the extent of experience in processing high rank coals in autoclave, bench scale and pilot scale equipment,
- a demonstrated commitment by the process developer to continue development of his process to at least a large scale continuous pilot plant stage.

Distillate product yields projected by NCB for the NCB/BP LSE process are substantially above 40 percent and are attractive provided that they can be confirmed in continuous pilot plant testing. During discussions with NCB/BP, firm confirmation should be obtained that continued development of their process, in the form of construction and operation of the proposed 25 tonne per day Point of Ayr pilot plant, will take place. As the NCB/BP process is in the early stages of development, successful demonstration at the 25 tonne per day scale is essential before serious consideration can be given to the process. Development of this pilot plant is heavily dependent on financial backing by private industry. To date, this financial backing has not been confirmed and design and construction of the pilot plant is being delayed.

DECISION POINT - Upon completion of the evaluation of alternate B.C. coals and discussions with coal liquefaction process developers, all information will be thoroughly evaluated to determine whether one,

two or zero continuous bench scale test programs should be commissioned. To warrant testing, distillate product yields significantly in excess of 40 percent should be expected, with reasonable assurances from the process developers.

If two processes are to be tested, it is recommended that one process be the NCB/BP process and the other process be one of the two direct liquefaction processes, H-Coal or Ruhrkohle/Veba.

5.3 COAL TESTING

If the decision is made to proceed with coal testing, continuous bench scale testing should be performed to further evaluate one or two coal liquefaction processes. The main objectives of the continous bench scale testing will be:

- to demonstrate the integrated process under optimum operating conditions,
- to generate yield and hydrogen consumption data under 'simulated' commercial scale conditions,
- to provide raw product samples for analysis and subsequent upgrading tests.

The continuous testing should be conducted in an integrated bench scale unit that tests all major steps in the coal liquefaction process simultaneously, including coal slurrying, reaction, product separation, recycle oil preparation and, in the NCB/BP case, filtration and hydrocracking. If process simulation, particularly recycle oil operation, is conducted in a stepwise manner, distillate oil yields and product losses may not be totally representative of continuous operation.

DECISION POINT - At the completion of the continuous bench scale test program, the test data will be thoroughly evaluated to determine whether or not further development of the coal liquefaction.

project is warranted and which process is best suited to the nominated coal. For the project to proceed, the test data should confirm a high distillate oil yield from the nominated B.C. coal, such that there would be a reasonable chance that overall project economics would be better than given in this prefeasibility study. In addition to distillate oil yield, other economic factors that might be different than those used in this evaluation should be considered in making this decision.

5.4 ADDITIONAL TESTING

If the decision is made to continue the development program, continuous laboratory scale testing of raw product hydrotreating should be performed to demonstrate the technology required to successfully upgrade the raw coal-derived products to specification transportation fuels or, alternatively, industrial fuels.

In addition, Texaco Development Corporation should be commissioned to prepare a standard Type-C process package for their residue gasification process, feeding vacuum residue or filtered solids from the selected coal liquefaction process.

Details of this program cannot be defined until the coal liquefaction process has been selected. For the NCB/BP process, only limited raw product upgrading is required as the final step in their process is a hydrocracking step which produces distillate fractions close to transportation fuel specifications. However, raw products produced by the direct liquefaction processes, H-Coal and Ruhrkohle/Veba, require substantial upgrading to meet transportation fuel specifications. Similarly, residues from the two types of processes (the NCB/BP extraction and the direct liquefaction) are markedly different and must be processed in different manners in the residue gasification process.

5.5 TECHNICAL AND ECONOMIC EVALUATION

A technical and economic evaluation of one coal liquefaction process would be performed only if the results of the continuous coal liquefaction bench scale test program were sufficiently encouraging to warrant continued development. As discussed in Section 5.3, a decision would be made at the conclusion of the test program as to whether or not further work would be performed and which process (if two were tested) was best suited to process the nominated B.C. coal.

5.5.1 Engineering Evaluation

The study would incorporate design concepts for the various plant components in sufficient detail as required to prepare cost estimates with an accuracy of ±25% for the selected process. The items to be developed and prepared will incorporate:

- a review of process packages and test data from the selected coal liquefaction process developer, the hydrotreater licensor and Texaco for the residue gasification process,
- obtain process data on other process facilities, including coal preparation, light ends recovery, hydrogen recovery and purification, sour gas scrubbing, sulphur plant and air separation plant,
- preparation of conceptual flowsheets for each process unit,
- determination of product slate for the plant,
- preparation of preliminary flow sheets for offsite facilities including product tankage, effluent treatment, flare system, etc.,
- preparation of preliminary flowsheets for utility systems including steam, air, water and plant fuel systems,
- preparation of material and energy balances for the various plant components,
- determination of catalyst and chemical requirements,

- determination of utility requirements including electricity, steam, cooling water, plant air, instrument air, water, natural gas, etc.,
- determination of operating manpower requirements,
- preparation of conceptual plot plans and layout drawings,
- identification and sizing of major items of equipment and preparation of an equipment list,
- preparation of preliminary project execution plans and schedules, including construction manpower requirements.

5.5.2 Estimating

Capital and operating cost estimates will be prepared based on cost data provided by the selected licensors and on the drawings and data developed through the Engineering activities outlined above.

Equipment vendors will be contacted for budget prices on major items of equipment for the project. This information together with cost data obtained from the licensors and other in-house data will be incorporated in an overall project estimate with an accuracy of ±25%.

Operating cost estimates for the complete plant, including cost of manpower, utilities, catalysts, chemicals, feedstocks and maintenance will be prepared. These estimates will be based on data provided by the licensors and in-house experience.

These estimates will form the basis for the economic and financial evaluation of the selected process.

5.5.3 Financial Feasibility

Close co-operation between the Consortium and the Consultant will be required during the performance of this task. The basic parameters, assumptions and other variables will be jointly established in order to develop an appropriate economic model for this analysis.

Discounted cash flows will be developed with various combinations of financial structures and several probability factors. These will include elements such as equity participation by government, accelerated depreciation, preferential tax treatment, phased investments, preferential freight rates, government development of infrastructures including shipping facilities, services, roads, energy supplies, etc.

The financial analysis will cover the projected life span of the project with jointly agreed upon interest rates, escalation, internal rate of return, etc. This task will include manipulation of variables individually or in combination to permit the generation of sensitivity and risk analyses.

5.5.4 Socio-Economic Evaluation

In estimating the social/economic benefits which the proposed complex will have on the region and the province, a number of factors will be investigated and evaluated. These factors include:

- housing and infrastructure capacity
- availability of employment and manpower skills
- an evaluation of the probable sources of non-local workers required for construction and operating phases and characteristics of incoming employees
- available manpower training programs and probability of their adaptation to suit the project requirements
- anticipated competition for skilled labour demand resulting from other major projects
- the expected personal incomes and forecasted spending patterns
- the nature and extent of demands on community services which will be required as a result of the project

- impact on commercial services such as hotels/motels, restaurants and other economic spin-offs
- impact on municipal services such as water and sewerage systems
- effects of the project on transportation modes by road, rail and air
- evaluation of municipal, regional and provincial revenues
- effects of forecasted distribution pattern of construction expenditures and sales revenues.

5.5.5 Environmental Overview

Appropriate government and regulatory agencies will be contacted at the earliest possible stage to obtain all stipulations and guidelines which need to be observed for the execution and operation of the project. This task will include a concise overview identifying those impacts which are likely to occur during the construction and operation of the project. This analysis will be based on available information specific to the selected site and will focus on physical and natural components of the environment.

Factors to be considered in evaluating impacts on physical environment include:

- source and quantity of water requirement and its impact on existing water bodies or ground water
- potential for increase in erosion and sedimentation due to site preparation activities
- effect of drawdown, increased discharges and changes in ambient temperature as a result of plant operation
- evaluation of liquid effluents and gaseous emissions and the potential impacts on water and air quality.

Effects on natural environment will include an analysis of terrestial and aquatic ecologies. This analysis will address concerns relative to present species, sensitive habitats, fisheries, communities and vegetation.

Kilborn and Badger have followed standard professional procedures in preparing the contents of this Report. It is based in part on details, information and assumptions provided by others and Kilborn and Badger, therefore, cannot guarantee the correctness of the Report; but to the extent of their investigation and within the scope of the work delegated to them, Kilborn and Badger believe the Report is substantially correct.